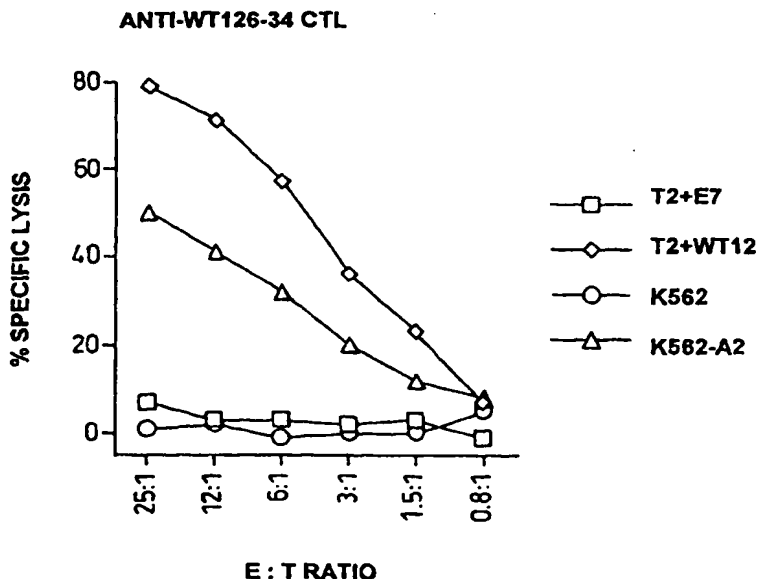


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## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification <sup>7</sup> : <b>C07K 14/47, 4/12, 7/06, A61K 38/08</b>		<b>A1</b>	(11) International Publication Number: <b>WO 00/26249</b> (43) International Publication Date: <b>11 May 2000 (11.05.00)</b>
(21) International Application Number: <b>PCT/GB99/03572</b> (22) International Filing Date: <b>2 November 1999 (02.11.99)</b> (30) Priority Data: <b>9823897.5</b> <b>2 November 1998 (02.11.98)</b> <b>GB</b> (71) Applicant (for all designated States except US): <b>IMPERIAL COLLEGE INNOVATIONS LIMITED [GB/GB];</b> Sherfield Building, Imperial College, London SW7 2AZ (GB). (72) Inventors; and (75) Inventors/Applicants (for US only): <b>STAUSS, Hans, Josef [DE/GB];</b> Dept. of Immunology, Imperial College School of Medicine, The Hammersmith Hospital, Du Cane Road, London W12 0NN (GB). <b>GAO, Liqueun [CN/GB];</b> Dept. of Immunology, Imperial College School of Medicine, The Hammersmith Hospital, Du Cane Road, London W12 0NN (GB). (74) Agent: <b>MILES, John, S.;</b> Eric Potter Clarkson, Park View House, 58 The Ropewalk, Nottingham NG1 5DD (GB).			(81) Designated States: <b>AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).</b>  <b>Published</b> <i>With international search report.</i>

(54) Title: IMMUNOTHERAPEUTIC METHODS USING EPITOPES OF WT-1 AND GATA-1



## (57) Abstract

A peptide comprising the amino acid sequence RMFPNAPYL or a portion or variant thereof provided that the peptide is not intact human WT-1 polypeptide or a peptide comprising the amino acid sequence CMTWNQMNL or a portion or variant thereof provided that the peptide is not intact human WT-1 polypeptide or a peptide comprising the amino acid sequence HLMPPFGPLL or a portion or variant thereof provided that the peptide is not intact human gata-1 polypeptide, and polynucleotides encoding these peptides. The peptides and polynucleotides are useful as cancer vaccines.

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## IMMUNOTHERAPEUTIC METHODS USING EPITOPES OF WT-1 AND GATA-1

The present invention relates to immunotherapeutic methods, and molecules and cells for use in immunotherapeutic methods. In particular,  
5 the present invention relates to the immunotherapy of cancer including leukaemia.

There is evidence that anti-tumour cytotoxic T lymphocytes (CTL) play an important role *in vivo*. Tumour reactive CTL have been shown to mediate  
10 tumour regression in animal models (Kast *et al* (1989) *Cell* 59, 603-614) and in man (Kawakami *et al* (1994) *Proc. Natl. Acad. Sci. USA* 91, 6458-6462). As with all types of anti-tumour therapy, a problem that needs to be overcome is that the therapy must destroy or inactivate the target tumour cells to a useful extent but that the therapy must not destroy or  
15 inactivate non-tumour cells to a deleterious extent. In other words, it is desirable if the therapy is selective for tumour cells to a beneficial extent.

Much of the current work on immunotherapy of cancer makes use of the fact that certain tumours express polypeptides which are not expressed in  
20 the equivalent non-tumour tissue, or makes use of the fact that the tumour expresses a mutant form of a polypeptide which is not expressed in the non-tumour tissue. However, it is not always possible to identify polypeptides in a tumour which fall into this category, and so other target polypeptides which can form the basis of an immunotherapeutic approach  
25 have been identified.

Work in melanoma patients has shown that peptide-epitopes recognised by melanoma-reactive CTL are frequently derived from tissue-specific

differentiation antigens. Recognition of differentiation antigens which are expressed in normal tissues seems to violate the rules of immunological tolerance; however, the CTL recognition of melanoma-associated differentiation antigens could be explained by the fact that they are  
5 normally only expressed in melanocytes which exist in relative small numbers at immunologically privileged sites, thus failing to establish tolerance. There is also evidence that prostate-specific differentiation antigens can serve as targets for CTL against tumours of the prostate. To  
10 what extent developmentally regulated transcription factors can serve as targets for CTL against tumours aberrantly expressing these factors is currently unknown.

Gata-1 is a transcription factor which is normally expressed in the erythroid, megacaryocyte, eosinophil and mast cell lineages and in  
15 multipotential progenitors. Aberrant expression of this tightly controlled transcription factor is observed in leukaemia, including CML and AML (Shimamoto *et al* (1995) *Blood* 86, 3173-3180).

In adults, expression of WT1, an embryonic transcription factor, has been  
20 observed in renal podocytes, in the testis, in the ovary, in breast myoepithelial cells and in some CD34<sup>+</sup> stem cells in the bone marrow. Aberrant expression was observed in breast cancer, ovarian cancer, melanoma and leukaemia including CML and AML (see, for example, Menssen *et al* (1995) *Leukaemia* 9, 1060-1067; Inoue *et al* (1997) *Blood*  
25 89, 1405-1412; Inoue *et al* (1996) *Blood* 88, 2267-2278; Inoue *et al* (1998) *Blood* 91, 2969-2976; Menssen *et al* (1997) *Int. J. Cancer* 70, 518-523; Menssen *et al* (1995) *Leukemia* 9, 1060-1067; Ogawa *et al* (1998) *Transplant* 21, 527-527; Rodeck *et al* (1994) *Int. J. Cancer* 59, 78-82;

Silberstein *et al* (1997) *Proc. Natl. Acad. Sci. USA* **94**, 8132-8137; Tamaki *et al* (1996) *Blood* **88**, 4396-4398; and Viel *et al* (1994) *Int. J. Cancer* **57**, 515-521).

5 US Patent No. 5,726,288 relates to the localisation and characterisation of the Wilms' tumour gene. Four amino acid *sequences* are disclosed (SEQ ID Nos 2, 4, 5 and 6) which contain either the sequence RMFPNAPYL or CMTWMNQMNL, but there is no disclosure of *peptides* corresponding to these sequences or of their use in immuno therapy.

10

Using an unconventional approach employing allo-MHC-restricted CTL, we have surprisingly identified peptide epitopes in the proteins WT-1 and gata-1 which may be presented by HLA-A0201 class I molecules and displayed on the surface of tumour cells expressing these proteins  
15 endogenously. HLA-A0201 negative responder individuals were used as a source of CTL specific for peptides presented by HLA-A0201 class I molecule, and this approach allows identification of HLA-A0201 presented peptides independent of possible tolerance of autologous CTL.

20 HLA-A0201 is the most common HLA-A haplotype.

For the avoidance of doubt, the terms HLA and MHC are used interchangeably in this specification.

25 A first aspect of the invention provides a peptide comprising the amino acid sequence RMFPNAPYL or a portion or variant thereof provided that the peptide is not the intact human WT-1 polypeptide.

A second aspect of the invention provides a peptide comprising the amino acid sequence CMTWNQMNL or a portion or variant thereof provided that the peptide is not the intact human WT-1 polypeptide.

- 5 A third aspect of the invention provides a peptide comprising the amino acid sequence HLMPFPGPLL or a portion or variant thereof provided that the peptide is not the intact human gata-1 polypeptide.

By "peptide" we include not only molecules in which amino acid residues are joined by peptide (-CO-NH-) linkages but also molecules in which the peptide bond is reversed. Such retro-inverso peptidomimetics may be made using methods known in the art, for example such as those described in Mézière *et al* (1997) *J. Immunol.* 159, 3230-3237, incorporated herein by reference. This approach involves making pseudopeptides containing changes involving the backbone, and not the orientation of side chains. Mézière *et al* (1997) show that, at least for MHC class II and T helper cell responses, these pseudopeptides are useful. Retro-inverse peptides, which contain NH-CO bonds instead of CO-NH peptide bonds, are much more resistant to proteolysis.

20

Similarly, the peptide bond may be dispensed with altogether provided that an appropriate linker moiety which retains the spacing between the C $\alpha$  atoms of the amino acid residues is used; it is particularly preferred if the linker moiety has substantially the same charge distribution and substantially the same planarity of a peptide bond.

25

It will be appreciated that the peptide may conveniently be blocked at its N- or C-terminus so as to help reduce susceptibility to exoproteolytic digestion.

- 5 By a "portion" of the given amino acid sequence we mean at least six consecutive amino acids of the given sequence such that the peptide is still able to bind to an HLA molecule in substantially the same way as a peptide consisting of the given amino acid sequence.
- 10 By a "variant" of the given amino acid sequence we mean that the side chains of, for example, one or two of the amino acid residues are altered (for example by replacing them with the side chain of another naturally occurring amino acid residue or some other side chain) such that the peptide is still able to bind to an HLA molecule in substantially the same
- 15 way as a peptide consisting of the given amino acid sequence. For example, a peptide may be modified so that it at least maintains, if not improves, the ability to interact with and bind a suitable MHC molecule, such as HLA-A0201, and so that it at least maintains, if not improves, the ability to generate activated CTL which can recognise and kill cells which
- 20 aberrantly express a polypeptide which contains an amino acid sequence as defined in the first or second or third aspect of the invention (for example, WT1 or gata-1, as the case may be). Positions 2 and 9 of an HLA-A2-binding nonamer are typically anchor residues. Modifications of these and other residues involved in binding HLA-A2 may enhance binding without
- 25 altering CTL recognition (for example, see Tourdot *et al* (1997) *J. Immunol.* 159, 2391-2398).

Those amino acid residues that are not essential to interact with the T cell receptor can be modified by replacement with another amino acid whose incorporation does not substantially effect T cell reactivity and does not eliminate binding to the relevant MHC.

5

Thus, apart from the proviso given, the peptide of the invention may be any peptide (by which term we include oligopeptide or polypeptide) which includes the amino acid sequences or a portion or variant thereof as given. Typically, the peptide of the invention is one which, if expressed in an  
10 antigen presenting cell, may be processed so that a fragment is produced which is able to bind to an appropriate MHC molecule and may be presented by a suitable cell and elicit a suitable T cell response. It will be appreciated that a fragment produced from the peptide may also be a peptide of the invention. Conveniently, the peptide of the invention  
15 contains a portion which includes the given amino acid sequence or a portion or variant thereof and a further portion which confers some desirable property. For example, the further portion may include a further T cell epitope (whether or not derived from the same polypeptide as the first T cell epitope-containing portion) or it may include a carrier  
20 protein or peptide. Thus, in one embodiment the peptide of the invention is a truncated human WT-1 protein or a fusion protein of a WT-1 protein fragment and another polypeptide portion provided that the human WT-1 portion includes the amino acid sequence RMFPNAPYL or CMTWNQMNL or both. In another embodiment the peptide of the  
25 invention is a truncated human gata-1 protein or a fusion protein of a human gata-1 protein fragment and another polypeptide portion provided that the human gata-1 portion includes the amino acid sequence HLMPFPGPLL.



In a particularly preferred embodiment, the peptide of the invention includes the amino acid sequence as given in the first, second or third aspect of the invention and at least one further T cell epitope wherein the further T cell epitope is able to facilitate the production of a T cell response directed at the type of tumour that aberrantly expresses WT-1 or gata-1. Thus, the peptides of the invention include so-called "beads on a string" polypeptides which can be used as vaccines.

The peptides of the invention may be of any size, but typically they may be less than 100 000 in molecular weight, preferably less than 50 000, more preferably less than 10 000 and typically about 5 000. In terms of the number of amino acid residues, the peptides of the invention may have fewer than 1000 residues, preferably fewer than 500 residues, more preferably fewer than 100 residues.

It will be appreciated from the following that in some applications the peptides of the invention may be used directly (ie they are not produced by expression of a polynucleotide in a patient's cell or in a cell given to a patient); in such applications it is preferred that the peptide has fewer than 100 residues.

It is preferred if the peptides of the invention are able to bind to HLA-A0201; however, the peptides may also bind to other HLA types as well as HLA-A0201. It is particularly preferred if the peptides bind selectively to HLA-A0201.

The peptides of the invention are particularly useful in immunotherapeutic methods to target and kill cells which aberrantly express the WT1 polypeptide (Wilms' tumour gene product) or the gata-1 polypeptide. The gata-1 polypeptide was so-named because it is a transcription factor which  
5 binds to a gata-box which is present in the promoter regions of some genes. It has also been called NF-e1, GF-1 and Eryf-1. The amino acid sequences RMFPNAPYL and CMTWNQMNL are found at residues 126-134 and 235-243, respectively, of WT1; the amino acid sequence HLMPFPGPLL is found at residues 378-387 of gata-1. The WT-1 amino  
10 acid sequence is given in Gessler *et al* (1990) *Nature* 343, 774-778; and the gata-1 amino acid sequence is given in Zon *et al* (1990) *Proc. Natl. Acad. Sci. USA* 87, 668-672; both of these papers are incorporated herein by reference.

15 Since these specific peptides consisting of the given amino acid sequences bind to HLA-A0201 it is preferred that the peptides of the invention are ones which bind HLA-A0201 and when so bound the HLA-A0201-peptide complex, when present on the surface of a suitable antigen-presenting cell, is capable of eliciting the production of a CTL which recognises a cell  
20 which aberrantly expresses a polypeptide comprising the given amino acid sequence, such as the WT1 polypeptide with respect to the peptides of the first and second aspects of the invention, and such as the gata-1 polypeptide with respect to the peptides of the third aspect of the invention.

25

The WT1 polypeptide is aberrantly expressed in leukaemias, breast cancer, melanoma and ovarian cancer; the gata-1 polypeptide is aberrantly expressed in leukaemias.

By "aberrantly expressed" we include the meaning that the polypeptide is overexpressed compared to normal levels of expression or that the gene is silent in the tissue from which the tumour is derived but in the tumour it is expressed. By "overexpressed" we mean that the polypeptide is present at a level at least 1.2 x that present in normal tissue; preferably at least 2 x and more preferably at least 5 x or 10 x the level present in normal tissue.

It is well known that an optimum length for a peptide to bind to an HLA molecule is around 8 to 12 amino acid, preferably 9 amino acids.

Particularly preferred peptides of the invention are those consisting of the amino acid sequences RMFPNAPYL or CMTWNQMNL or HLMPFPGPLL.

15

If a peptide which is greater than around 12 amino acid residues is used directly to bind to a MHC molecule, it is preferred that the residues that flank the core HLA binding region are ones that do not substantially affect the ability of the peptide to bind to the MHC molecule or to present the peptide to the CTL. However, it will be appreciated that larger peptides may be used, especially when encoded by a polynucleotide, since these larger peptides may be fragmented by suitable antigen-presenting cells.

Peptides (at least those containing peptide linkages between amino acid residues) may be synthesised by the Fmoc-polyamide mode of solid-phase peptide synthesis as disclosed by Lu *et al* (1981) *J. Org. Chem.* **46**, 3433 and references therein. Temporary N-amino group protection is afforded by the 9-fluorenylmethyloxycarbonyl (Fmoc) group. Repetitive cleavage

25

of this highly base-labile protecting group is effected using 20% piperidine in N,N-dimethylformamide. Side-chain functionalities may be protected as their butyl ethers (in the case of serine threonine and tyrosine), butyl esters (in the case of glutamic acid and aspartic acid), butyloxycarbonyl derivative (in the case of lysine and histidine), trityl derivative (in the case of cysteine) and 4-methoxy-2,3,6-trimethylbenzenesulphonyl derivative (in the case of arginine). Where glutamine or asparagine are C-terminal residues, use is made of the 4,4'-dimethoxybenzhydryl group for protection of the side chain amido functionalities. The solid-phase support is based on a polydimethyl-acrylamide polymer constituted from the three monomers dimethylacrylamide (backbone-monomer), bisacryloylethylene diamine (cross linker) and acryloylsarcosine methyl ester (functionalising agent). The peptide-to-resin cleavable linked agent used is the acid-labile 4-hydroxymethyl-phenoxyacetic acid derivative. All amino acid derivatives are added as their preformed symmetrical anhydride derivatives with the exception of asparagine and glutamine, which are added using a reversed N,N-dicyclohexyl-carbodiimide/1-hydroxybenzotriazole mediated coupling procedure. All coupling and deprotection reactions are monitored using ninhydrin, trinitrobenzene sulphonic acid or isotin test procedures. Upon completion of synthesis, peptides are cleaved from the resin support with concomitant removal of side-chain protecting groups by treatment with 95% trifluoroacetic acid containing a 50% scavenger mix. Scavengers commonly used are ethanedithiol, phenol, anisole and water, the exact choice depending on the constituent amino acids of the peptide being synthesised. Trifluoroacetic acid is removed by evaporation *in vacuo*, with subsequent trituration with diethyl ether affording the crude peptide. Any scavengers present are removed by a simple extraction procedure which on

lyophilisation of the aqueous phase affords the crude peptide free of scavengers. Reagents for peptide synthesis are generally available from Calbiochem-Novabiochem (UK) Ltd, Nottingham NG7 2QJ, UK. Purification may be effected by any one, or a combination of, techniques  
5 such as size exclusion chromatography, ion-exchange chromatography and (principally) reverse-phase high performance liquid chromatography. Analysis of peptides may be carried out using thin layer chromatography, reverse-phase high performance liquid chromatography, amino-acid analysis after acid hydrolysis and by fast atom bombardment (FAB) mass  
10 spectrometric analysis.

A further aspect of the invention provides a polynucleotide encoding a peptide as defined in the first or second or third aspects of the invention. The polynucleotide may be DNA or RNA and it may or may not contain  
15 introns so long as it codes for the peptide. Of course, it is only peptides which contain naturally occurring amino acid residues joined by naturally-occurring peptide bonds which are encodable by a polynucleotide.

A still further aspect of the invention provides an expression vector  
20 capable of expressing a polypeptide according to the first or second or third aspects of the invention.

A variety of methods have been developed to operably link polynucleotides, especially DNA, to vectors for example *via*  
25 complementary cohesive termini. For instance, complementary homopolymer tracts can be added to the DNA segment to be inserted to the vector DNA. The vector and DNA segment are then joined by

hydrogen bonding between the complementary homopolymeric tails to form recombinant DNA molecules.

Synthetic linkers containing one or more restriction sites provide an  
5 alternative method of joining the DNA segment to vectors. The DNA  
segment, generated by endonuclease restriction digestion as described  
earlier, is treated with bacteriophage T4 DNA polymerase or *E. coli* DNA  
polymerase I, enzymes that remove protruding, 3'-single-stranded termini  
with their 3'-5'-exonucleolytic activities, and fill in recessed 3'-ends with  
10 their polymerizing activities.

The combination of these activities therefore generates blunt-ended DNA  
segments. The blunt-ended segments are then incubated with a large  
molar excess of linker molecules in the presence of an enzyme that is able  
15 to catalyze the ligation of blunt-ended DNA molecules, such as  
bacteriophage T4 DNA ligase. Thus, the products of the reaction are  
DNA segments carrying polymeric linker sequences at their ends. These  
DNA segments are then cleaved with the appropriate restriction enzyme  
and ligated to an expression vector that has been cleaved with an enzyme  
20 that produces termini compatible with those of the DNA segment.

Synthetic linkers containing a variety of restriction endonuclease sites are  
commercially available from a number of sources including International  
Biotechnologies Inc, New Haven, CN, USA.

25

A desirable way to modify the DNA encoding the polypeptide of the  
invention is to use the polymerase chain reaction as disclosed by Saiki *et*  
*al* (1988) *Science* 239, 487-491. This method may be used for introducing

the DNA into a suitable vector, for example by engineering in suitable restriction sites, or it may be used to modify the DNA in other useful ways as is known in the art.

5 In this method the DNA to be enzymatically amplified is flanked by two specific primers which themselves become incorporated into the amplified DNA. The said specific primers may contain restriction endonuclease recognition sites which can be used for cloning into expression vectors using methods known in the art.

10

The DNA (or in the case of retroviral vectors, RNA) is then expressed in a suitable host to produce a polypeptide comprising the compound of the invention. Thus, the DNA encoding the polypeptide constituting the compound of the invention may be used in accordance with known  
15 techniques, appropriately modified in view of the teachings contained herein, to construct an expression vector, which is then used to transform an appropriate host cell for the expression and production of the polypeptide of the invention. Such techniques include those disclosed in US Patent Nos. 4,440,859 issued 3 April 1984 to Rutter *et al*, 4,530,901  
20 issued 23 July 1985 to Weissman, 4,582,800 issued 15 April 1986 to Cowl, 4,677,063 issued 30 June 1987 to Mark *et al*, 4,678,751 issued 7 July 1987 to Goeddel, 4,704,362 issued 3 November 1987 to Itakura *et al*, 4,710,463 issued 1 December 1987 to Murray, 4,757,006 issued 12 July 1988 to Toole, Jr. *et al*, 4,766,075 issued 23 August 1988 to Goeddel *et al* and 4,810,648 issued 7 March 1989 to Stalker, all of which are  
25 incorporated herein by reference.

The DNA (or in the case of retroviral vectors, RNA) encoding the polypeptide constituting the compound of the invention may be joined to a wide variety of other DNA sequences for introduction into an appropriate host. The companion DNA will depend upon the nature of the host, the manner of the introduction of the DNA into the host, and whether episomal maintenance or integration is desired.

Generally, the DNA is inserted into an expression vector, such as a plasmid, in proper orientation and correct reading frame for expression. If necessary, the DNA may be linked to the appropriate transcriptional and translational regulatory control nucleotide sequences recognised by the desired host, although such controls are generally available in the expression vector. The vector is then introduced into the host through standard techniques. Generally, not all of the hosts will be transformed by the vector. Therefore, it will be necessary to select for transformed host cells. One selection technique involves incorporating into the expression vector a DNA sequence, with any necessary control elements, that codes for a selectable trait in the transformed cell, such as antibiotic resistance. Alternatively, the gene for such selectable trait can be on another vector, which is used to co-transform the desired host cell.

Host cells that have been transformed by the recombinant DNA of the invention are then cultured for a sufficient time and under appropriate conditions known to those skilled in the art in view of the teachings disclosed herein to permit the expression of the polypeptide, which can then be recovered.



Many expression systems are known, including bacteria (for example *E. coli* and *Bacillus subtilis*), yeasts (for example *Saccharomyces cerevisiae*), filamentous fungi (for example *Aspergillus*), plant cells, animal cells and insect cells.

5

The vectors typically include a prokaryotic replicon, such as the ColE1 *ori*, for propagation in a prokaryote, even if the vector is to be used for expression in other, non-prokaryotic, cell types. The vectors can also include an appropriate promoter such as a prokaryotic promoter capable of directing the expression (transcription and translation) of the genes in a bacterial host cell, such as *E. coli*, transformed therewith.

A promoter is an expression control element formed by a DNA sequence that permits binding of RNA polymerase and transcription to occur. Promoter sequences compatible with exemplary bacterial hosts are typically provided in plasmid vectors containing convenient restriction sites for insertion of a DNA segment of the present invention.

Typical prokaryotic vector plasmids are pUC18, pUC19, pBR322 and pBR329 available from Biorad Laboratories, (Richmond, CA, USA) and pTrc99A and pKK223-3 available from Pharmacia, Piscataway, NJ, USA.

A typical mammalian cell vector plasmid is pSVL available from Pharmacia, Piscataway, NJ, USA. This vector uses the SV40 late promoter to drive expression of cloned genes, the highest level of expression being found in T antigen-producing cells, such as COS-1 cells.

An example of an inducible mammalian expression vector is pMSG, also available from Pharmacia. This vector uses the glucocorticoid-inducible promoter of the mouse mammary tumour virus long terminal repeat to drive expression of the cloned gene.

5

Useful yeast plasmid vectors are pRS403-406 and pRS413-416 and are generally available from Stratagene Cloning Systems, La Jolla, CA 92037, USA. Plasmids pRS403, pRS404, pRS405 and pRS406 are Yeast Integrating plasmids (YIps) and incorporate the yeast selectable markers  
10 *HIS3*, *TRP1*, *LEU2* and *URA3*. Plasmids pRS413-416 are Yeast Centromere plasmids (Ycps).

Other vectors and expression systems are well known in the art for use with a variety of host cells.

15

The present invention also relates to a host cell transformed with a polynucleotide vector construct of the present invention. The host cell can be either prokaryotic or eukaryotic. Bacterial cells may be preferred prokaryotic host cells in some circumstances and typically are a strain of  
20 *E. coli* such as, for example, the *E. coli* strains DH5 available from Bethesda Research Laboratories Inc., Bethesda, MD, USA, and RR1 available from the American Type Culture Collection (ATCC) of Rockville, MD, USA (No ATCC 31343). Preferred eukaryotic host cells include yeast, insect and mammalian cells, preferably vertebrate cells such  
25 as those from a mouse, rat, monkey or human fibroblastic and kidney cell lines. Yeast host cells include YPH499, YPH500 and YPH501 which are generally available from Stratagene Cloning Systems, La Jolla, CA 92037, USA. Preferred mammalian host cells include Chinese hamster ovary

(CHO) cells available from the ATCC as CCL61, NIH Swiss mouse embryo cells NIH/3T3 available from the ATCC as CRL 1658, monkey kidney-derived COS-1 cells available from the ATCC as CRL 1650 and 293 cells which are human embryonic kidney cells. Preferred insect cells  
5 are Sf9 cells which can be transfected with baculovirus expression vectors.

Transformation of appropriate cell hosts with a DNA construct of the present invention is accomplished by well known methods that typically depend on the type of vector used. With regard to transformation of  
10 prokaryotic host cells, see, for example, Cohen *et al* (1972) *Proc. Natl. Acad. Sci. USA* 69, 2110 and Sambrook *et al* (1989) *Molecular Cloning, A Laboratory Manual*, Cold Spring Harbor Laboratory, Cold Spring Harbor, NY. Transformation of yeast cells is described in Sherman *et al* (1986) *Methods In Yeast Genetics, A Laboratory Manual*, Cold Spring  
15 Harbor, NY. The method of Beggs (1978) *Nature* 275, 104-109 is also useful. With regard to vertebrate cells, reagents useful in transfecting such cells, for example calcium phosphate and DEAE-dextran or liposome formulations, are available from Stratagene Cloning Systems, or Life Technologies Inc., Gaithersburg, MD 20877, USA.

20

Electroporation is also useful for transforming and/or transfecting cells and is well known in the art for transforming yeast cell, bacterial cells, insect cells and vertebrate cells.

25 For example, many bacterial species may be transformed by the methods described in Luchansky *et al* (1988) *Mol. Microbiol.* 2, 637-646 incorporated herein by reference. The greatest number of transformants is

consistently recovered following electroporation of the DNA-cell mixture suspended in 2.5X PEB using 6250V per cm at 25 $\mu$ FD.

Methods for transformation of yeast by electroporation are disclosed in  
5 Becker & Guarente (1990) *Methods Enzymol.* 194, 182.

Successfully transformed cells, ie cells that contain a DNA construct of the present invention, can be identified by well known techniques. For example, cells resulting from the introduction of an expression construct  
10 of the present invention can be grown to produce the polypeptide of the invention. Cells can be harvested and lysed and their DNA content examined for the presence of the DNA using a method such as that described by Southern (1975) *J. Mol. Biol.* 98, 503 or Berent *et al* (1985) *Biotech.* 3, 208. Alternatively, the presence of the protein in the  
15 supernatant can be detected using antibodies as described below.

In addition to directly assaying for the presence of recombinant DNA, successful transformation can be confirmed by well known immunological methods when the recombinant DNA is capable of directing the expression  
20 of the protein. For example, cells successfully transformed with an expression vector produce proteins displaying appropriate antigenicity. Samples of cells suspected of being transformed are harvested and assayed for the protein using suitable antibodies.

25 Thus, in addition to the transformed host cells themselves, the present invention also contemplates a culture of those cells, preferably a monoclonal (clonally homogeneous) culture, or a culture derived from a monoclonal culture, in a nutrient medium.

It will be appreciated that certain host cells of the invention are useful in the preparation of the peptides of the invention, for example bacterial, yeast and insect cells. However, other host cells may be useful in certain  
5 therapeutic methods. For example, antigen-presenting cells, such as dendritic cells, may usefully be used to express the peptides of the invention such that they may be loaded into appropriate MHC molecules.

A further aspect of the invention provides a method of producing a peptide  
10 of the first or second or third aspect of the invention, the method comprising culturing host cells which contain a polynucleotide or expression vector which encodes the peptide and obtaining the peptide from the host cell or culture medium.

15 Further aspects of the invention provide pharmaceutical compositions which comprise a pharmaceutically acceptable carrier and a peptide according to the first, second or third aspects of the invention or a polynucleotide or expression vector encoding such a peptide. The pharmaceutical formulation is prepared in a form suitable for  
20 administration to a patient and is sterile and pyrogen free. Still further aspects of the invention provide a peptide according to any of the first or second or third aspects of the invention, or polynucleotides or expression vectors encoding such a peptide, for use in medicine. The peptides or polynucleotides or expression vectors are packaged and presented for use  
25 in medicine.

The pharmaceutical composition, or the package and presentation, may be in any suitable form. It is envisaged that suitable forms are for

intravenous (i.v.) injection, sub-cutaneous (s.c.) injection, intradermal (i.d.) injection, intraperitoneal (i.p.) injection, intramuscular (i.m.) injection.

- 5 Preferred ways of peptide injection are s.c., i.d., i.p., i.m., and i.v.

Preferred ways of DNA injection are i.d., i.m., s.c., i.p. and i.v.

Doses of between 1 and 500 mg of peptide or DNA may be given.

10

- A further aspect of the invention provides a method of killing target cells in a patient which target cells aberrantly express a polypeptide comprising an amino acid sequence of any of the first or second or third aspects of the invention, the method comprising administering to the patient an effective  
15 amount of a peptide according to any of the first or second or third aspects of the invention, or an effective amount of a polynucleotide or an expression vector encoding a said peptide, wherein the amount of said peptide or amount of said polynucleotide or expression vector is effective to provoke an anti-target cell immune response in said patient.

20

The target cell is typically a tumour or cancer cell. Typically the tumour or cancer cell is one which aberrantly expresses WT1 or gata-1.

- The peptide or peptide-encoding nucleic acid constitutes a tumour or  
25 cancer vaccine. It may be administered directly into the patient, into the affected organ or systemically, or applied *ex vivo* to cells derived from the patient or a human cell line which are subsequently administered to the patient, or used *in vitro* to select a subpopulation from immune cells

derived from the patient, which are then re-administered to the patient. If the nucleic acid is administered to cells *in vitro*, it may be useful for the cells to be transfected so as to co-express immune-stimulating cytokines, such as interleukin-2. The peptide may be substantially pure, or combined  
5 with an immune-stimulating adjuvant such as Detox, or used in combination with immune-stimulatory cytokines, or be administered with a suitable delivery system, for example liposomes. The peptide may also be conjugated to a suitable carrier such as keyhole limpet haemocyanin (KLH) or mannan (see WO 95/18145 and Longenecker *et al* (1993) *Ann.*  
10 *NY Acad. Sci.* **690**, 276-291). The peptide may also be tagged, or be a fusion protein, or be a hybrid molecule. The peptides whose sequence is given in the first or second or third aspects of the invention are expected to stimulate CD8 CTL. However, stimulation is more efficient in the presence of help provided by CD4 T cells. Thus, the fusion partner or  
15 sections of a hybrid molecule suitably provide epitopes which stimulate CD4 T cells. CD4 stimulating epitopes are well known in the art and include those identified in tetanus toxoid. The polynucleotide may be substantially pure, or contained in a suitable vector or delivery system. Suitable vectors and delivery systems include viral, such as systems based  
20 on adenovirus, vaccinia virus, retroviruses, herpes virus, adeno-associated virus or hybrids containing elements of more than one virus. Non-viral delivery systems include cationic lipids and cationic polymers as are well known in the art of DNA delivery. Physical delivery, such as *via* a "gene-gun" may also be used. The peptide or peptide encoded by the  
25 nucleic acid may be a fusion protein, for example with an epitope from tetanus toxoid which stimulates CD4 T cells.

The peptide for use in a cancer vaccine may be any suitable peptide. In particular, it may be a suitable 9-mer peptide or a suitable 7-mer or 8-mer or 10-mer peptide. Longer peptides may also be suitable, but 9-mer or 10-mer peptides are preferred. It may be advantageous, when the cancer vaccine is to be used in relation to WT1-expressing cancers if peptides of both the first and second aspects of the invention are used, or that a peptide is used which contains both of the sequences given in the first and second aspects of the invention.

- 10 Suitably, any nucleic acid administered to the patient is sterile and pyrogen free. Naked DNA may be given intramuscularly or intradermally or subcutaneously. The peptides may be given intramuscularly, intradermally or subcutaneously.
- 15 Vaccination results in CTL responses stimulated by professional antigen-presenting cells; once CTL are primed, there may be an advantage in enhancing MHC expression in tumour cells.

It may also be useful to target the vaccine to specific cell populations, for example antigen presenting cells, either by the site of injection, use of targeting vectors and delivery systems, or selective purification of such a cell population from the patient and *ex vivo* administration of the peptide or nucleic acid (for example dendritic cells may be sorted as described in Zhou *et al* (1995) *Blood* 86, 3295-3301; Roth *et al* (1996) *Scand. J. Immunology* 43, 646-651). For example, targeting vectors may comprise a tissue- or tumour-specific promoter which directs expression of the antigen at a suitable place.



Patients to whom the therapy is to be given, may have their tumours typed for overexpression or abnormal expression (both of which are aberrant expression) of WT1 or gata-1.

- 5 A further aspect of the invention therefore provides a vaccine effective against cancer, or cancer or tumour cells, comprising an effective amount of a peptide according to any one of the first or second or third aspects of the invention, or comprising a nucleic acid encoding such a peptide.
- 10 It is particularly preferred if the vaccine is a nucleic acid vaccine. It is known that inoculation with a nucleic acid vaccine, such as a DNA vaccine, encoding a polypeptide leads to a T cell response.

- Conveniently, the nucleic acid vaccine may comprise any suitable nucleic acid delivery means. The nucleic acid, preferably DNA, may be naked (ie  
15 with substantially no other components to be administered) or it may be delivered in a liposome or as part of a viral vector delivery system.

- It is believed that uptake of the nucleic acid and expression of the encoded  
20 polypeptide by dendritic cells may be the mechanism of priming of the immune response; however, dendritic cells may not be transfected but are still important since they may pick up expressed peptide from transfected cells in the tissue.

- 25 It is preferred if the vaccine, such as DNA vaccine, is administered into the muscle. It is also preferred if the vaccine is administered onto the skin.

The nucleic acid vaccine may be administered without adjuvant. The nucleic acid vaccine may also be administered with an adjuvant such as BCG or alum. Other suitable adjuvants include Aquila's QS21 stimulon (Aquila Biotech, Worcester, MA, USA) which is derived from saponin,  
5 mycobacterial extracts and synthetic bacterial cell wall mimics, and proprietary adjuvants such as Ribi's Detox. Quil A, another saponin-derived adjuvant, may also be used (Superfos, Denmark). It is preferred if the nucleic acid vaccine is administered without adjuvant.

- 10 Other adjuvants such as Freund's may also be useful. It may also be useful to give the peptide conjugated to keyhole limpet haemocyanin, preferably also with an adjuvant.

Polynucleotide-mediated immunization therapy of cancer is described in  
15 Conry *et al* (1996) *Seminars in Oncology* 23, 135-147; Condon *et al* (1996) *Nature Medicine* 2, 1122-1127; Gong *et al* (1997) *Nature Medicine* 3, 558-561; Zhai *et al* (1996) *J. Immunol.* 156, 700-710; Graham *et al* (1996) *Int J. Cancer* 65, 664-670; and Burchell *et al* (1996) pp 309-313  
In: Breast Cancer, Advances in biology and therapeutics, Calvo *et al*  
20 (eds), John Libbey Eurotext, all of which are incorporated herein by reference.

A still further aspect of the present invention provides the use of a peptide according to the first or second or third aspect of the invention, or of a  
25 polynucleotide or expression vector encoding such a peptide, in the manufacture of a medicament for killing target cells in a patient which target cells aberrantly express a polypeptide comprising an amino acid sequence as defined in the first or second or third aspects of the invention.

Thus, the medicament is useful in treating cancers which aberrantly express WT1 or gata-1.

A further aspect of the invention provides a method for producing  
5 activated cytotoxic T lymphocytes (CTL) *in vitro*, the method comprising  
contacting *in vitro* CTL with antigen-loaded human class I MHC  
molecules expressed on the surface of a suitable antigen-presenting cell for  
a period of time sufficient to activate, in an antigen specific manner, said  
CTL wherein the antigen is a peptide according to any one of the first or  
10 second or third aspects of the invention.

Suitably, the CTL are CD8<sup>+</sup> cells but they may be CD4<sup>+</sup> cells. The  
MHC class I molecules may be expressed on the surface of any suitable  
cell and it is preferred if the cell is one which does not naturally express  
15 MHC class I molecules (in which case the cell is transfected to express  
such a molecule) or, if it does, it is defective in the antigen-processing or  
antigen-presenting pathways. In this way, it is possible for the cell  
expressing the MHC class I molecule to be primed substantially  
completely with a chosen peptide antigen before activating the CTL.

20

The antigen-presenting cell (or stimulator cell) typically has an MHC class  
I molecule on its surface and preferably is substantially incapable of itself  
loading said MHC class I molecule with the selected antigen. As is  
described in more detail below, the MHC class I molecule may readily be  
25 loaded with the selected antigen *in vitro*.

Conveniently, said antigen-presenting cell is a mammalian cell defective in  
the expression of a peptide transporter such that, when at least part of said

selected molecule is a peptide, it is not loaded into said MHC class I molecule.

Preferably the mammalian cell lacks or has a reduced level or has reduced  
5 function of the TAP peptide transporter. Suitable cells which lack the TAP peptide transporter include T2, RMA-S and *Drosophila* cells. TAP is the Transporter Associated with antigen Processing.

Thus, conveniently the cell is an insect cell such as a *Drosophila* cell.

10

The human peptide loading deficient cell line T2 is available from the American Type Culture Collection, 12301 Parklawn Drive, Rockville, Maryland 20852, USA under Catalogue No CRL 1992; the *Drosophila* cell line Schneider line 2 is available from the ATCC under Catalogue No  
15 CRL 19863; the mouse RMA-S cell line is described in Karre and Ljunggren (1985) *J. Exp. Med.* 162, 1745, incorporated herein by reference.

In a preferred embodiment the stimulator cell is a host cell (such as a T2,  
20 RMA-S or *Drosophila* cell) transfected with a nucleic acid molecule capable of expressing said MHC class I molecule. Although T2 and RMA-S cells do express before transfection HLA class I molecules they are not loaded with a peptide.

25 Mammalian cells can be transfected by methods well known in the art. *Drosophila* cells can be transfected, as described in Jackson *et al* (1992) *proc. Natl. Acad. Sci. USA* 89, 12117, incorporated herein by reference.

Conveniently said host cell before transfection expresses substantially no MHC class I molecules.

It is also preferred if the stimulator cell expresses a molecule important for  
5 T cell costimulation such as any of B7.1, B7.2, ICAM-1 and LFA 3.

The nucleic acid sequences of numerous MHC class I molecules, and of the costimulator molecules, are publicly available from the GenBank and EMBL databases.

10

It is particularly preferred if substantially all said MHC class I molecules expressed in the surface of said stimulator cell are of the same type.

HLA class I in humans, and equivalent systems in other animals, are  
15 genetically very complex. For example, there are at least 110 alleles of the HLA-B locus and at least 90 alleles of the HLA-A locus. Although any HLA class I (or equivalent) molecule is useful in this aspect of the invention, it is preferred if the stimulator cell presents at least part of the selected molecule in an HLA class I molecule which occurs at a  
20 reasonably high frequency in the human population. It is well known that the frequency of HLA class I alleles varies between different ethnic groupings such as Caucasian, African, Chinese and so on. At least as far as the Caucasian population is concerned it is preferred that HLA class I molecule is encoded by an HLA-A2 allele, or an HLA-A1 allele or an  
25 HLA-A3 allele or an HLA-B27 allele. HLA-A2 is particularly preferred.

In a further embodiment, combinations of HLA molecules may also be used. For example, a combination of HLA-A2 and HLA-A3 covers 74% of the Caucasian population.

5 The use of recombinant polyepitope vaccines for the delivery of multiple CD8 CTL epitopes is described in Thomson *et al* (1996) *J. Immunol.* 157, 822-826 and WO 96/03144, both of which are incorporated herein by reference. In relation to the present invention, it may be desirable to include in a single vaccine, a peptide (or a nucleic acid encoding a  
10 peptide) wherein the peptide includes, in any order, the amino acid sequence RMFPNAPYL, CMTWNQMNL, HLMPFPGPLL and a CD4 T cell-stimulating epitope (such as from tetanus toxoid). Such a vaccine would be particularly useful for treating cancers which express WT-1 and gata-1. Such "bead-on-a-string" vaccines are typically DNA vaccines.

15

A convenient method of activating CTL (CD8<sup>+</sup> cells) is described in WO 93/17095, incorporated herein by reference. The method of WO 93/17095 raises CTL against peptides presented by syngeneic (ie autologous) HLA class I molecules.

20

A number of other methods may be used for generating CTL *in vitro*. For example, the methods described in Peoples *et al* (1995) *Proc. Natl. Acad. Sci. USA* 92, 432-436 and Kawakami *et al* (1992) *J. Immunol.* 148, 638-643 use autologous tumour-infiltrating lymphocytes in the generation of  
25 CTL. Plebanski *et al* (1995) *Eur. J. Immunol.* 25, 1783-1787 makes use of autologous peripheral blood lymphocytes (PLBs) in the preparation of CTL. Jochmus *et al* (1997) *J. Gen. Virol.* 78, 1689-1695 describes the

production of autologous CTL by employing pulsing dendritic cells with peptide or polypeptide, or *via* infection with recombinant virus.

Hill *et al* (1995) *J. Exp. Med.* 181, 2221-2228 and Jerome *et al* (1993) *J.*  
5 *Immunol.* 151, 1654-1662 make use of B cells in the production of autologous CTL. In addition, macrophages pulsed with peptide or polypeptide, or infected with recombinant virus, may be used in the preparation of autologous CTL.

10 Allogeneic cells may also be used in the preparation of CTL and this method is described in detail in WO 97/26328, incorporated herein by reference. For example, in addition to *Drosophila* cells and T2 cells, other cells may be used to present antigens such as CHO cells, baculovirus-infected insects cells, bacteria, yeast, vaccinia-infected target  
15 cells. In addition plant viruses may be used (see, for example, Porta *et al* (1994) *Virology* 202, 449-955 which describes the development of cowpea mosaic virus as a high-yielding system for the presentation of foreign peptides.

20 It is preferred if allogeneic cells are used in the preparation of CTL so that the CTL are allo-MHC-restricted with respect to the peptides of the invention. It is particularly preferred that the CTL are from a HLA-A0201 negative responder individual and that the peptide is presented by a HLA-A0201 class I molecule by the antigen-presenting cell.

25

Exogenously applied peptides may be linked to a HIV tat peptide to direct them into the MHC Class I pathway for presentation by CTL (see, for example, Kim *et al* (1997) *J. Immunol.* 159, 1666-1668.

The activated CTL which are directed against the peptides of the invention are useful in therapy. Thus, a further aspect of the invention provides activated CTL obtainable by the foregoing methods of the invention.

5

A still further aspect of the invention provides activated CTL which selectively recognise a cell which aberrantly expresses a polypeptide comprising an amino acid sequence given in any of the first or second or third aspects of the invention. Preferably, the CTL recognises the said  
10 cell by binding to the peptide as defined in any of the first or second or third aspects of the invention.

The CTL are useful in a method of killing target cells in a patient which target cells aberrantly express a polypeptide comprising an amino acid  
15 sequence given in any one of the first or second or third aspects of the invention wherein the patient is administered an effective number of the activated CTL.

The CTL which are administered to the patient may be derived from the  
20 patient and activated as described above (ie they are autologous CTL). Alternatively, the CTL are not from the patient but are from another individual. Of course, it is preferred if the individual is a healthy individual. By "healthy individual" we mean that the individual is generally in good health, preferably has a competent immune system and,  
25 more preferably, is not suffering from any disease which can be readily tested for, and detected. In this embodiment, the CTL are derived from an individual whose HLA class I molecules are mismatched with those of the patient. Thus, it is preferred if the CTL are allo-restricted. Treatment



with allo-restricted CTL is described in my earlier patent application WO 97/26328, incorporated herein by reference.

Thus, the methods of the invention include methods of adoptive  
5 immunotherapy.

The activated CTL contain a T cell receptor (TCR) which is involved in recognising cells which express the aberrant polypeptide. It is useful if the cDNA encoding the TCR is cloned from the activated CTL and  
10 transferred into a further CTL for expression.

The TCRs of CTL clones of the invention (whether allo-restricted or self-restricted) specific for the peptides of the first or second or third aspects of the invention are cloned. The TCR usage in the CTL clones is determined  
15 using (i) TCR variable region-specific monoclonal antibodies and (ii) RT-PCR with primers specific for  $V\alpha$  and  $V\beta$  gene families. A cDNA library is prepared from poly-A mRNA extracted from the CTL clones. Primers specific for the C-terminal portion of the TCR  $\alpha$  and  $\beta$  chains and for the N-terminal portion of the identified  $V\alpha$  and  $\beta$  segments are used. The  
20 complete cDNA for the TCR  $\alpha$  and  $\beta$  chain is amplified with a high fidelity DNA polymerase and the amplified products cloned into a suitable cloning vector. The cloned  $\alpha$  and  $\beta$  chain genes may be assembled into a single chain TCR by the method as described by Chung *et al* (1994) *Proc. Natl. Acad. Sci. USA* 91, 12654-12658. In this single chain construct the  
25  $V\alpha J$  segment is followed by the  $V\beta DJ$  segment, followed by the C $\beta$  segment followed by the transmembrane and cytoplasmic segment of the CD3  $\zeta$  chain. This single chain TCR is then inserted into a retroviral expression vector (a panel of vectors may be used based on their ability to

infect mature human CD8<sup>+</sup> T lymphocytes and to mediate gene expression: the retroviral vector system Kat is one preferred possibility (see *Finer et al* (1994) *Blood* 83, 43). High titre amphotrophic retrovirus are used to infect purified CD8<sup>+</sup> T lymphocytes isolated from the peripheral blood of tumour patients following a protocol published by Roberts *et al* (1994) *Blood* 84, 2878-2889, incorporated herein by reference. Anti-CD3 antibodies are used to trigger proliferation of purified CD8<sup>+</sup> T cells, which facilitates retroviral integration and stable expression of single chain TCRs. The efficiency of retroviral transduction is determined by staining of infected CD8<sup>+</sup> T cells with antibodies specific for the single chain TCR. *In vitro* analysis of transduced CD8<sup>+</sup> T cells establishes that they display the same tumour-specific killing as seen with the allo-restricted CTL clone from which the TCR chains were originally cloned. Populations of transduced CD8<sup>+</sup> T cells with the expected specificity may be used for adoptive immunotherapy of the tumour patients. Patients may be treated with in between 10<sup>8</sup> to 10<sup>11</sup> (most likely 10<sup>9</sup>-10<sup>10</sup>) autologous, transduced CTL.

Other suitable systems for introducing genes into CTL are described in Moritz *et al* (1994) *Proc. Natl. Acad. Sci. USA* 91, 4318-4322, incorporated herein by reference. Eshhar *et al* (1993) *Proc. Natl. Acad. Sci. USA* 90, 720-724 and Hwu *et al* (1993) *J. Exp. Med.* 178, 361-366 also describe the transfection of CTL.

Thus, a further aspect of the invention provides a TCR which recognises a cell which aberrantly expresses a polypeptide comprising an amino acid sequence given in any one of the first or second or third aspects of the invention, the TCR being obtainable from the activated CTL.

As well as the TCR, functionally equivalent molecules to the TCR are included in the invention. These include any molecule which is functionally equivalent to a TCR which can perform the same function as  
5 a TCR. In particular, such molecules include genetically engineered three-domain single-chain TCRs as made by the method described by Chung *et al* (1994) *Proc. Natl. Acad. Sci. USA* 91, 12654-12658, incorporated herein by reference, and referred to above.

10 The invention also includes a polynucleotide encoding the TCR or functionally equivalent molecule, and an expression vector encoding the TCR or functionally equivalent molecule thereof. Expression vectors which are suitable for expressing the TCR of the invention include those described above in respect of expression of the peptides of the invention.  
15 It is, however, preferred that the expression vectors are ones which are able to express the TCR in a CTL following transfection.

A still further aspect of the invention provides a method of killing target cells in a patient which target cells aberrantly express a polypeptide  
20 comprising an amino acid sequence given in any of the first or second or third aspects of the invention, the method comprising the steps of (1) obtaining CTL from the patient; (2) introducing into said cells a polynucleotide encoding a TCR, or a functionally equivalent molecule, as defined above; and (3) introducing the cells produced in step (2) into the  
25 patient.

A still further aspect of the invention provides a method of killing target cells in a patient which target cells aberrantly express a polypeptide

comprising an amino acid sequence as defined in the first or second or third aspects of the invention, the method comprising the steps of (1) obtaining antigen presenting cells, such as dendritic cells, from said patient; (2) contacting said antigen presenting cells with a peptide as  
5 defined in the first or second or third aspects of the invention, or with a polynucleotide encoding such a peptide, *ex vivo*; and (3) reintroducing the so treated antigen presenting cells into the patient.

Preferably, the antigen presenting cells are dendritic cells.

10

Suitably, the dendritic cells are autologous dendritic cells which are pulsed with an antigenic peptide. The antigenic peptide may be any suitable antigenic peptide which gives rise to an appropriate T cell response. T-cell therapy using autologous dendritic cells pulsed with peptides from a  
15 tumour associated antigen is disclosed in Murphy *et al* (1996) *The Prostate* 29, 371-380 and Tjua *et al* (1997) *The Prostate* 32, 272-278.

In a further embodiment the antigen presenting cells, such as dendritic cells, are contacted with a polynucleotide which encodes a peptide of the  
20 invention. The polynucleotide may be any suitable polynucleotide and it is preferred that it is capable of transducing the dendritic cell thus resulting in the presentation of a peptide and induction of immunity.

Conveniently, the polynucleotide may be comprised in a viral  
25 polynucleotide or virus. For example, adenovirus-transduced dendritic cells have been shown to induce antigen-specific antitumour immunity in relation to MUC1 (see Gong *et al* (1997) *Gene Ther.* 4, 1023-1028). Similarly, adenovirus-based systems may be used (see, for example, Wan

*et al* (1997) *Hum. Gene Ther.* 8, 1355-1363); retroviral systems may be used (Specht *et al* (1997) *J. Exp. Med.* 186, 1213-1221 and Szabolcs *et al* (1997) *Blood* 90, 2160-2167); particle-mediated transfer to dendritic cells may also be used (Tuting *et al* (1997) *Eur. J. Immunol.* 27, 2702-2707);  
5 and RNA may also be used (Ashley *et al* (1997) *J. Exp. Med.* 186, 1177-1182).

It will be appreciated that, with respect to the methods of killing target cells in a patient, it is particularly preferred that the target cells are cancer  
10 cells.

The WT1 polypeptide comprises the amino acid sequences RMFPNA PYL and CMTWNQMNL, and it is aberrantly expressed in leukaemias, breast cancer, melanoma and ovarian cancer.

15

The gata-1 polypeptide comprises the amino acid sequence HLMPFPGPLL, and it is aberrantly expressed in leukaemias.

It is particularly preferred if the patients who are treated by the methods of  
20 the invention have the HLA-A0201 haplotype. Thus, in a preferred embodiment the HLA haplotype of the patient is determined prior to treatment. HLA haplotyping may be carried out using any suitable method; such methods are well known in the art.

25 The invention includes in particular the use of the peptides of the invention (or polynucleotides encoding them) for active *in vivo* vaccination; for manipulation of autologous dendritic cells *in vitro* followed by introduction of the so-manipulated dendritic cells *in vivo* to activate CTL

responses; to activate autologous CTL *in vitro* followed by adoptive therapy (ie the so-manipulated CTL are introduced into the patient); and to activate CTL from healthy donors (MHC matched or mismatched) *in vitro* followed by adoptive therapy.

5

The invention will now be described in more detail by reference to the following Figures and Examples in which:

Figure 1 shows the killing activity of anti-WT126-34 CTL. T2 is a human  
10 cell line with a peptide-loading defect which is available from the ATCC under Catalogue No CRL 1992. They are loaded with the WT126-34 peptide (RMFPNAPYL) (T2 + WT12) or with E7 control peptide (TLGIVCPI) which is an irrelevant HLA-A2-binding peptide (T2 + E7).

15 K562 is a leukaemia cell line and K562-A2 is the K562 leukaemia cell line transfected with HLA-A0201. The E:T ratio is the effector: target cell ratio. Specific lysis (%) is measured in a standard CTL assay such as that described in Sadovnikova & Stauss (1996) *Proc. Natl. Acad. Sci. USA* 93, 13114-13118, incorporated herein by reference.

20

Figure 2 shows the killing activity of anti-huWT126-34 CTL. Leuk-697, MV441 and BV173 are leukaemia cell lines. P12 stands for WT126-34 peptide (RMFPNAPYL).

25 Figure 3 shows the killing activity of an anti-hug 378-87 CTL. hug 378-87 is the peptide HLMPFPGPLL and hug 14 is an HLA-A2-binding control peptide (RLSPDLLTL). C1R-A2 is a human B-lymphoid cell line. K562-A2 human is a leukaemia cell line.

Figure 4 shows the specificity of allo-restricted CTL generated against the WT1-derived peptide P126. CTL were isolated by limiting dilution cloning of T lymphocyte bulk cultures from HLA-A0201<sup>-</sup> donors stimulated with HLA-A0201<sup>+</sup> stimulator cells coated with P126 peptide. (A) Isolated CTL lines killed the TAP-deficient T2 target cells coated with the immunising P126 peptide but not T2 cells coated with the HLA-A0201-binding E7 control peptide. (B) Peptide titration experiments showing that 3 anti-P126 CTL lines were of high avidity recognising low picomolar concentration of P126, and 3 CTL lines were of low avidity since nanomolar P126 concentration were required for target cell recognition. T2 cells coated with the indicated concentrations of P126 were used as CTL targets. High avidity CTL were used for all subsequent experiments because low avidity CTL did not recognise target cells expressing WT1 endogenously. (C) High avidity CTL kill the HLA-A0201<sup>+</sup> leukemic cell lines BV173, 697 but not the HLA-A0201<sup>+</sup>, EBV-transformed B-lymphoid cells C1R-A2. Coating of C1R-A2 with P126 resulted in efficient CTL killing. The HLA-A0201<sup>-</sup> leukemia cell line K562 is not killed by the CTL unless transfected with the HLA-A0201 gene.

Figure 5 shows WT1 RNA and protein expression in leukemic cell lines and in CD34<sup>+</sup> and CD34<sup>-</sup> cell populations freshly isolated from leukemia patients and normal donors. (A) RT-PCR to measure WT1 RNA in leukemic cell lines and in the B-lymphoid cell line C1R-A2. The same cell lines were used as CTL targets in figure 4C. The amplified WT1 product is 482 bp, The RNA of the house keeping ABL gene was amplified to

indicate the amount of RNA in each sample. The ABL product is 385 bp long. (B) RT-PCR to measure WT1 RNA expression in purified CD34<sup>+</sup> and CD34<sup>-</sup> cell populations from 4 CML patients and 3 normal donors. The leukemic cell line BV173 served as positive control for WT1 expression. Similar results were obtained with samples from additional 6 CML patients. (C) Western blotting to measure WT1 protein expression in leukemia cell lines and in purified CD34<sup>+</sup> and CD34<sup>-</sup> cell populations from 2 CML patients and 2 normal donors. The expression of the house keeping actin protein was used as indicator to control for the amount of protein present in each sample. The WT1 protein is approximately 54 kDa in size and the actin protein approximately 42 kDa.

Figure 6 is an analysis of CTL-mediated killing and inhibition of colony formation of CD34<sup>+</sup> cell populations purified from leukemic patients and normal donors. (A) Representative experiment showing the level of killing by anti-P126 CTL against purified CD34<sup>+</sup> and CD34<sup>-</sup> cell populations isolated from CML patients who were either HLA-A0201<sup>+</sup> or A0201<sup>-</sup>. CD34<sup>-</sup>/A0201<sup>+</sup> cells were not recognised by the CTL unless coated with P126 peptide. The leukemic cell line BV173 and the TAP-deficient T2 cells coated with P126 or the control E7 peptide were used as positive and negative controls in all experiments. (B) Average of the level of specific CTL killing of purified CD34<sup>+</sup> cells from 11 different HLA-A0201<sup>+</sup> CML patients and from 6 normal donors. The level of killing of CD34<sup>-</sup> cells purified from CML patients and against the positive control cells BV173 is also shown. The figure shows the mean level and standard deviation of specific CTL killing. (C) Representative experiment showing the level of killing by anti-P126 CTL of purified CD34<sup>+</sup> and CD34<sup>-</sup> cell



populations isolated from HLA-A0201<sup>+</sup> normal donors. No CTL killing was detectable unless target cells were coated with P126 peptide. (D) CTL-mediated inhibition of colony formation by purified CD34<sup>+</sup> cells co-cultured for 4 hours with CTL at an effector/target cell ratio of 10:1.

5 Untreated control CD34<sup>+</sup> cells were cultured under the same conditions without CTL. CTL treated and untreated control cells were then plated in methylcellulose and after 14 days the numbers of CFU-GM were counted. Shown is the percentage of CFU-GM after CTL treatment using the CFU-GM observed in the untreated controls as 100% reference. The figure

10 shows the mean and standard deviation of independent experiments with CD34<sup>+</sup> cells from 9 different HLA-A0201<sup>+</sup> CML patients, 7 different normal donors, and with CD34<sup>+</sup> cells from 5 different HLA-A0201<sup>+</sup> CML patients. (E) Colony formation by A0201<sup>+</sup>/CD34<sup>+</sup> CML cells that were untreated or treated for 4 hours with high avidity P126-specific CTL (line

15 81) or with low avidity CTL (line 85) prior to plating. Shown are CFU-GM and BFU-E using the number of colonies observed in the untreated controls as 100% reference. (F) Cold target competition experiment. Shown is the killing by anti-P126 CTL against chromium-labelled CD34<sup>+</sup> targets from a A0201<sup>+</sup> CML patient in the absence or presence of a 30

20 fold excess of cold BV173 and C1R-A2 targets. The killing of chromium-labelled BV173 and C1R-A2 is shown for comparison.

*Example 1: The identification of HLA-A0201 presented CTL epitopes in WT-1 and gata-1.*

25

Eight WT-1 peptides with HLA-A2 binding motifs were analysed and two were found to be natural CTL epitopes. Twelve gata-1 peptides with

HLA-A2 binding motifs were analysed and one was found to be a natural CTL epitope.

The following approach was used: i) analysis of synthetic peptides in  
5 HLA-A0201 binding assays; iii) use of HLA-A0201 binding peptides to  
stimulate CTL responses from HLA-A0201 negative individuals; iv) test  
of peptide-specific CTL against tumour cells expressing WT-1 or gata-1  
endogenously.

10 Peptide binding assay:  $5 \times 10^5$  T2 cells were incubated overnight (o/n) in  
96 well plates in 100 ml of RPMI 1640 medium with 5% boiled FCS (to  
destroy proteases) and varying concentrations of synthetic peptides. Wells  
containing T2 cells without peptides or known A2-binding peptides were  
used as negative and positive control, respectively. Following overnight  
15 incubation cells were washed and stained by indirect immunofluorescence  
for surface HLA-A2 with A-2 specific monoclonal antibodies HB54 and  
HB117 (American Type Culture Collection, ATCC). FACS analysis was  
performed on a Coulter Corporation flow cytometer (Haiteah, Florida).

20 Generation of allo-restricted CTL lines and clones: PBMC from HLA-A2  
negative buffy coat blood packs were used as responders. Each well of a  
24 well plate received  $2 \times 10^6$  Ficoll separated PBMC and  $2 \times 10^5$  stimulator  
cells. Stimulator cells were prepared by overnight incubation of T2 cells  
in 100  $\mu$ M peptide in RPMI with 5% boiled FCS. On day 5 T cells were  
25 harvested and plated in fresh T cell medium at a density of  $5 \times 10^5$  per well  
in a 24 well plate with the addition of  $2 \times 10^6$  autologous irradiated PBMC  
as feeders,  $2 \times 10^5$  peptide coated irradiated T2 or C1R-A2 cells, 500 nM  
peptide and 10% QS4120 culture supernatant to suppress outgrowth of

CD4 T cells. The cultures were fed every 2 weeks using HLA-A2 positive cell lines coated with the immunising peptide as stimulators. The bulk cultures were cloned in T cell medium at a density of 1, 10 and 30 cells per well.  $10^4$  peptide-coated T2 cells,  $2 \times 10^5$  HLA-A2 negative feeders and  
5 2 U IL-2 were added to each well. CTL obtained from microcultures seeded at 1 cell per well are further referred to as clones if the percentage of wells growing cells did not exceed 30%.

CTL assays:  $10^6$  T2 cells were incubated for 1 hr in 200  $\mu$ l of assay  
10 medium (RPMI 1640 with 5% heat inactivated FCS) with 100  $\mu$ M synthetic peptide at 37°C. Peptide coated and uncoated cells were  $^{51}\text{Cr}$ -labelled for an additional hour, washed and added to serial two-fold dilutions of effector cells in round bottom 96 well plates to obtain a total volume of 200  $\mu$ l/well. CTL bulk lines were analysed in the presence of  
15 30 cold K562 cells per  $^{51}\text{Cr}$ -labelled target cell to reduce the background killing caused by NK cells. To test the sensitivity of T cell clones serial dilutions of peptides in assay medium were made in 96 well plates.  $5 \times 10^3$   $^{51}\text{Cr}$ -labelled T2 cells were added to each well to obtain a total volume of 100  $\mu$ l and incubated for 1 hr. Effector cells were added at an E:T ratio  
20 sufficient for maximal CTL killing. Assay plates were incubated at 37°C, 5%  $\text{CO}_2$  and after 4h 100  $\mu$ l of supernatant was harvested from each well and counted using a Wallac Gamma Counter. The specific lysis was calculated by the equation (experimental release-spontaneous release)/(maximum release-spontaneous release) x 100%.

### Results

In the WT-1 protein two CTL recognised peptide epitopes expressed in WT-1 expressing tumour cells were identified:

5

WT126-34:RMFPNAPYL

WT235-43:CMTWNQMNL

10 These are 9 amino acid long peptides and are likely to represent the minimal epitope required for efficient recognition by CTL.

The killing activity of CTL against the WT126-34 is shown in the following table:

Target cell	HLA-A0201 expression	WT-1 expression	Killing by anti-WT126-34 CTL
leukaemia cell line BV173	yes	yes	yes
leukaemia cell line Leuk-697	yes	yes	yes
leukaemia cell line MV441	no	yes	no
leukaemia cell line K562	no	yes	no
leukaemia cell line K562 transfected with HLA-A0201	yes	yes	yes
freshly isolated CD34+ leukemic cells from A0201-positive patients	yes	yes	yes
freshly isolated CD34+ leukaemic cells from A0201-negative patients	no	yes	no
breast cancer cell line MDA-MB231	yes	yes	yes
C1R-A2 cell line	yes	no	no
EBV transformed cells from A0201-positive patients	yes	no	no

The data in the table illustrate that CTL against the WT126-34 peptide kill tumour cells expressing WT-1 and HLA-A0201. WT-1 negative B lymphoblastoid cells are not killed. Figure 1 and 2 show representative experiments illustrating the killing activity of anti-WT126-34 CTL.

The data set obtained with anti-WT235-43 CTL is not as extensive as the data obtained with WT126-34 CTL. It is clear, however, that anti-

WT235-43 CTL kill HLA-A0201-positive tumour cells expressing WT-1 endogenously.

In the gata-1 protein one CTL recognised peptide epitopes expressed in  
5 gata-1 expressing tumour cells was identified: Hug 378-87  
HLMPFPGPLL.

This is a 10 amino acid long peptides and are likely to represent the minimal epitope required for efficient recognition by CTL.

10

CTL against this peptide can recognise the HLA-A0201 transfected K562 leukaemia cell line expressing gata-1 endogenously, while untransfected K562 cells are not recognised.

15 Conclusion

CTL recognised peptide epitopes in WT-1 and gata-1 have been identified. These epitopes are displayed on tumour cells aberrantly expressing these proteins. The physiological expression of WT-1 and gata-1 is limited to a  
20 relatively small number of normal cells. Thus, it is possible that autologous CTL show limited tolerance to these proteins and that the identified CTL epitopes can be used for vaccination against tumours with aberrant WT-1 and gata-1 expression, respectively, and in other immunotherapeutic methods.

25

*Example 2: Production of activated cytotoxic lymphocytes (CTL) using Class I molecules and the WT1 peptide antigen RMFPNAPYL and their administration*

- 5 Activated cytotoxic T lymphocytes (CTLs) are produced using HLA-A2 Class I molecules and the nonamer peptide from WT1: RMFPNAPYL.

The method described in PCT patent application WO 93/17095 is used to make the CTLs. *Drosophila* cells are used to present the peptide antigen  
10 to CTL. The HLA-A2 molecule is expressed in the *Drosophila* cells.

The peptide is synthesised on an Applied Biosystems synthesiser, ABI 431A (Foster City, CA, USA) and subsequently purified by HPLC.

- 15 As is described in detail in WO 93/17095, in order to optimize the *in vitro* conditions for the generation of specific cytotoxic T cells, the culture of stimulator cells is maintained in an appropriate medium. The stimulator cells are *Drosophila* cells as described in WO 93/17095, which are preferably maintained in serum-free medium (eg Excell 400).

20

Prior to incubation of the stimulator cells with the cells to be activated, eg precursor CD8 cells, an amount of antigenic peptide is added to the stimulator cell culture, of sufficient quantity to become loaded onto the human Class I molecules to be expressed on the surface of the stimulator  
25 cells. A sufficient amount of peptide is an amount that will allow about 200, and preferably 200 or more, human Class I MHC molecules loaded with peptide to be expressed on the surface of each stimulator cell. The stimulator cells are typically incubated with  $>20 \mu\text{g/ml}$  peptide.

Resting or precursor CD8 cells are then incubated in culture with the appropriate stimulator cells for a time period sufficient to activate the CD8 cells. The CD8 cells shall thus be activated in an antigen-specific manner.

5 The ratio of resting or precursor CD8 (effector) cells to stimulator cells may vary from individual to individual and may further depend upon variables such as the amenability of an individual's lymphocytes to culturing conditions. The lymphocyte:stimulator cell (*Drosophila* cell) ratio is typically in the range of about 30:1 to 300:1. For example, 3 x

10  $10^7$  human PBL and  $1 \times 10^6$  live *Drosophila* cells are admixed and maintained in 20 ml of RPMI 1640 culture medium.

The effector/stimulator culture are maintained for as long a time as is necessary to stimulate a therapeutically usable or effective number of CD8

15 cells. The optimum time is typically between about one and five days, with a "plateau", ie a "maximum" specific CD8 activation level, generally being observed after five days of culture. *In vitro* activation of CD8 cells is typically detected within a brief period of time after transfection of a cell line. Transient expression in a transfected cell line capable of

20 activating CD8 cells is detectable within 48 hours of transfection. This clearly indicates that either stable or transient cultures of transformed cells expressing human Class I MHC molecules are effective in activating CD8 cells.

25 Activated CD8 cells may be effectively separated from the stimulator (*Drosophila*) cells using monoclonal antibodies specific for the stimulator cells, for the peptides loaded onto the stimulator cells, or for the CD8 cells (or a segment thereof) to bind their appropriate complementary



ligand. Antibody-tagged molecules are then extracted from the stimulator-effector cell admixture *via* immunoprecipitation or immunoassay methods.

Effective, cytotoxic amounts of the activated CD8 cells can vary between  
5 *in vitro* and *in vivo* uses, as well as with the amount and type of cells that are the ultimate target of these killer cells between about  $1 \times 10^6$  and  $1 \times 10^{12}$  activated CTL are used for adult humans.

The activated CD8 cells are harvested from the *Drosophila* cell culture  
10 prior to administration of the CD8 cells to the individual being treated. It is important to note, however, that unlike other present and proposed treatment modalities, the method described in this Example uses a cell culture system (ie *Drosophila* cells) that are not tumorigenic. Therefore, if complete separation of *Drosophila* cells and activated CD8 cells is not  
15 achieved, there is no inherent danger known to be associated with the administration of a small number of *Drosophila* cells, whereas administration of mammalian tumor-promoting cells may be hazardous.

Methods of re-introducing cellular components are used such as those  
20 exemplified in US Patent No 4,844,893 to Honsik *et al* and US Patent No 4,690,915 to Rosenberg. For example, administration of activated CD8 cells via intravenous infusion is appropriate.

***Example 3: Dendritic cells pulsed with the WT1 peptide CMTWNQMNL  
25 for treating breast cancer***

Breast carcinoma is potentially curable only when truly localised. The most common problem is either late presentation with overt metastases or,

more frequently, the development of systemic metastases after apparent local cure. Metastatic breast carcinoma is highly chemosensitive and effective chemotherapy routinely induces disease remission, allowing delay in the onset of secondary disease or amelioration of the symptoms of extensive disease.

This type of immunotherapy is based on the proposition that tumour growth and dissemination reflects a failure in immunological surveillance, either due to reduction in antigen presentation by the neoplastic cells or due to generalised decline in patient immunity. There is evidence that both mechanisms occur in breast carcinoma and in particular that there are important deficiencies in dendritic cell (DC) function (Gabrilovich *et al* (1997) *Clin. Cancer Res.* 3, 483-490). Cytotoxic T cell responses are demonstrated *in vitro* to immunogenic peptides such as the WT1 peptide CMTWNQMNL. DC are professional antigen-processing and -presenting cells which are critical to the development of primary MHC-restricted T-cell immunity. They originate from a CD34<sup>+</sup> precursor in bone marrow, but can also be derived from a post colony-forming unit CD14<sup>+</sup> intermediate in the peripheral blood. DC migrate to peripheral sites in skin, mucosa, spleen and thymus. They have been implicated in a variety of clinically important processes, including allograft rejection, atopic disorders, autoimmunity and anti-tumour immunity.

The patient is typed as HLA-A2.

DC are cultured *ex vivo* from CD34<sup>+</sup> stem cells or CD14<sup>+</sup> peripheral blood monocytes using cytokines, principally GM-CSF, IL-4 and TNF $\alpha$ . DC from both these sources are immunocompetent and can take up